IV. "Aberration Problems: a Discussion concerning the Connexion between Ether and Matter, and the Motion of the Ether near the Earth." By Oliver Lodge, F.R.S., Professor of Physics, University College, Liverpool. Received March 31, 1892.

(Abstract.)

The paper begins by recognising the distinction between ether in free space and ether as modified by transparent matter, and points out that the modified ether, or at least the modification, necessarily travels with the matter. The well-known hypothesis of Fresnel is discussed and re-stated in modern form.

Of its two parts, one has been verified by the experiment of Fizeau, the other has not yet been verified. Its two parts are, (1) that inside transparent matter the velocity of light is affected by the motion of that matter, and (2) that immediately outside moving matter there is no such effect. The author proceeds to examine into the truth of this second part, (1) by discussing what is already known, (2) by fresh experiment.

The phenomena resulting from motion are four, viz.:—

1. Changes in direction, observed by telescope and called aberration.
2. Change in frequency, observed by spectroscope and called Doppler effect.
3. Change in time of journey, observed by lag of phase or shift of interference bands.
4. Change in intensity, observed by energy received by thermopile.

After a discussion of the effects of motion in general, which differ according as projectiles or waves are contemplated, the case of a fixed source in a moving medium is considered; then of a moving source in a fixed medium; then the case of medium alone moving past source and receiver; and, finally, of the receiver only moving.

It is found that the medium alone moving causes no change in direction, no change in frequency, no detectable lag of phase, and probably no change of intensity; and hence arises the difficulty of ascertaining whether the general body of the ether is moving relatively to the earth or not.

A clear distinction has to be drawn, however, between the effect of general motion of the medium as a whole and motion of parts of the medium, as when dense matter is artificially moved. The latter kind of motion may produce many effects which the former cannot.

A summary of this part of the discussion is as follows:—

Source alone moving produces a real and apparent change of colour; a real but not apparent error in direction; no lag of

phase, except that appropriate to altered wave-length; a change of intensity corresponding to different wave-lengths.

Medium alone moving, or source and receiver moving together, gives no change of colour; no change of direction; a real lag of phase, but undetectable without control over the medium; a change of intensity corresponding to different distances, but compensated by change of radiating power.

Receiver alone moving gives an apparent change of colour; an apparent change of direction; no change of phase, except that appropriate to extra virtual speed of light; change of intensity corresponding to different virtual velocity of light.

The probable absence of a first order effect of any kind, due to ethereal drift or relative motion between earth and ether, makes it necessary to attend to second order effects.

The principle of least time is applied, after the manner of Lorentz, to define a ray rigorously and to display the effect of existence or non-existence of a velocity potential. Fresnel's law is seen to be equivalent to extending the velocity potential throughout all transparent matter.

It is shown that a ray traversing space or transparent substances will retain its shape, whatever the motion of the medium, so long as that motion is irrotational, and that in that case the apparent direction of objects depends simply on motion of observer; but, on the other hand, that if the earth drags with it some of the ether in its neighbourhood, stellar rays will be curved, and astronomical aberration will be a function of latitude and time of day.

The experiment of Boscovich, Airy, and Hoek, as to the effect of filling a telescope-tube with water, does not discriminate between these theories. For if the ether is entirely non-viscous and has a velocity potential, stellar rays continue straight, in spite of change of medium (or at oblique incidence are repeated in the simple manner), and there will be no fresh effect due to change of medium; while, if, on the contrary, the ether is all carried along near the earth, then it is stationary in a telescope tube, whether that be filled with water or air, and likewise no effect is to be expected. In the case of a viscous ether, all the difficulty of aberration must be attacked in the upper layers above the earth; all the bending is over by the time the surface is reached. It is difficult to see how an ethereal drift will not tend to cause an aberration in the wrong direction.

Of the experiments hitherto made by Arago, Babinet, Maxwell, Mascart, Hoek, and perhaps others, though all necessary to be tried, not one really discriminates between the rival hypotheses. All are consistent either with absolute quiescence of ether near moving bodies, or with relative quiescence near the earth's surface. They may be said, perhaps, to be inconsistent with any intermediate position.

Two others, however, do appear to discriminate; viz., an old and difficult polarisation experiment of Fizeau,* which has not been repeated since, and the recent famous experiment of Michelson with rays made to interfere after traversing and retraversing paths at right angles.

The conclusions deducible from these two experiments are antagonistic. Fizeau's appears to uphold absolute rest of ether; Michelson's upholds relative rest, *i.e.*, drag by the earth.

The author now attempts a direct experiment as to the effect of moving matter on the velocity of light in its neighbourhood; assuming that a positive or negative result with regard to the effect of motion on the velocity of light will be accepted as equivalent to a positive or negative result, with respect to the motion of the ether.

He gives a detailed account of the experiment, the result of which is to show that such a mass as a pair of circular saws clamped together does not whirl the ether between the plates to any appreciable amount, not so much, for instance, as a 1/500th part of their speed. He surmises, therefore, that the ether is not appreciably viscous. But, nevertheless, it may perhaps be argued that enormous masses may act upon it gravitationally, straining it so as perhaps to produce the same sort of effect as if they dragged it with them. He proposes to try the effect of a larger mass. Also to see if, when subject to a strong magnetic field, ether can be dragged by matter.

The aberrational effect of slabs of moving transparent matter is considered, also the effect of a different refractive medium.

Motion of medium, though incompetent to produce any aberrational or Doppler effect, is shown to be able to slightly modify them if otherwise produced.

The Doppler effect is then entered into. The question is discussed as to what the deviation produced by a prism or a grating really depends on: whether on frequency or wave-length. It is shown that whereas the effect of a grating must be independent of its motion and depend on wave-length alone, yet that the effect observed with a moving grating by a moving observer depends on frequency, because the motion of the observer superposes an aberrational effect on the true effect of the grating. This suggests a means of discriminating motion of source from motion of observer; in other words, of detecting absolute motion through ether; but the smallness of the difference is not hopeful.

Michelson's experiment is then discussed in detail, as a case of normal reflexion from a moving mirror or from a mirror in a drifting medium. No error in its theory is discovered.

The subjects of change of phase, of energy, of reflexion in a moving

* 'Ann. de Chim. et de Phys.,' 1859.

† 'Phil. Mag.,' 1887.

medium, work done on a moving mirror, and the laws of reflexion and refraction as modified by motion, are considered.

It is found that the law of reflexion is not really obeyed in a relatively moving medium, though to an observer stationary with respect to the mirror it appears to be obeyed, so far as the first order of aberration magnitude is concerned; but that there is a residual discrepancy involving even powers of aberration magnitude, of an amount possibly capable of being detected by very delicate observation.

The following statements are made and justified :—

(1.) The planes of incidence and reflexion are always the same.

(2.) The angles of incidence and reflexion, measured between ray and normal to surface, usually differ.

(3.) If the mirror is stationary and medium moving, they differ by a quantity depending on the square of aberration magnitude, *i.e.*, by 1 part in 100,000,000; and a stationary telescope, if delicate enough, might show the effect.

(4.) If the medium is moving and mirror stationary, the angles differ by a quantity depending on the first power of aberration magnitude (1 part in 10,000), but a telescope moving with the mirror will not be able to observe it; for the commonplace aberration caused by motion of receiver will obliterate the odd powers and leave only the even ones; the same as in case (3).

(5.) As regards the angles which the incident and reflected *waves* make with the surface, they differ in case (3) by a first order magnitude, in case (4) by a second order magnitude.

(6.) At grazing incidence the ordinary laws are accurately obeyed. At normal incidence the error is a maximum.

(7.) The ordinary laws are obeyed when the direction of drift is either tangential or normal to the mirror; and are disobeyed most when the drift is at 45°.

(8.) In general, the shape of the incident wave is not precisely preserved after reflexion in a moving medium. To a parallel beam the mirror acts as if slightly tilted; to a conical beam as if slightly curved. But either effect, as observable in the result, is almost hopelessly small.

(9.) Similar statements are true for refraction, assuming Fresnel's law.

The possibility of obtaining first order effects from general ethereal motion by means of electrical observations is considered.